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A Novel Approach for Making Dynamic Range Measurements in Radio Frequency Front Ends for Software Controlled Radio Architectures

by Gregory Mitchell and Christian Fazi

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REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2007	Final	Fiscal Year 2006 to 2007

4. TITLE AND SUBTITLE

A Novel Approach for Making Dynamic Range Measurements in Radio Frequency Front Ends for Software Controlled Radio Architectures

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Gregory Mitchell and Christian Fazi

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: AMSRD-ARL-SE-RE
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER

ARL-TR-4235

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

P&D Army Mission Funds
Army Research Laboratory Adelphi Laboratory Center
2800 Powder Mill Rd
Adelphi, MD 20906-1197

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

ARL-TR-4235

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A novel setup to perform two-tone spurious-free dynamic range (SFDR) measurements on a mixer using a single analog input port is introduced. When access to the intermediate frequency (IF) port in a radio frequency (RF) front-end circuit is not available, the traditional two-port method for making an SFDR measurement is inadequate. Passing the analog input through a directional coupler between the RF combiner and the mixer facilitates the performance of the traditional third order intermodulation (IMD) test. Key differences between the single-port and traditional two-port setups are explained, and experimental data obtained using the single-port setup is compared to data obtained using the traditional two-port setup for two different mixer models. This data confirms that while the single-port approach yields similar results, a calibration to account for the additional losses introduced by the directional coupler is needed.

15. SUBJECT TERMS

Spurious free dynamic range (SFDR), two-tone, intermodulation (IMD), radio frequency identification (RFID), mixer, single port, directional coupler, software controlled radio

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
			SAR	18	Gregory Mitchell
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U			(301) 394-2322

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1. Introduction

Spurious-free dynamic range (SFDR) is an important characteristic for determining the robustness of any radio frequency (RF) front end-circuit. The non-linear mixing process, which converts the received signal to intermediate frequency (IF) for lowpass filtering, creates intermodulations (IMDs) that may appear in the filter's bandpass region. The basis for the SFDR measurement is how large the RF power of interfering signals must be before IMDs appear within the passband of the receiver's lowpass filter.

The traditional way to measure SFDR is to analyze this behavior with the output of the IF port displayed on a spectrum analyzer. With the increasing popularity of active RF identification (RFID), in the form of software controlled radio, traditional methods for measuring the SFDR of the receiver become impractical when the output is digital. Reduced form factors for RF circuits signify that in active RFID radio architectures, often the mixer and analog-to-digital converter (ADC) are housed within the same integrated circuit (IC) chip; therefore, the analog IF port needed to perform the standard SFDR measurement may not be available. This report introduces a novel approach for performing SFDR measurements of digital radio architectures when the user does not have access to an analog IF output. The results of the new one-port method will be compared to those of the traditional two-port method, and the need for calibration to correlate the results of the new approach to those of the standard approach will be discussed.

2. Circuit and Method Descriptions

2.1   Two-port Measurement Setup

The two-port SFDR measurement setup references the analog RF input and analog IF output ports of the mixer. Figure 1 gives a representation of the setup used to evaluate the SFDR characteristics introduced by a mixer within the receiver of an RF system. For simplicity, the bandpass filter, demodulator, and lowpass filter elements of a conventional RF receiver are ignored. The RF signals are directly injected into the system.
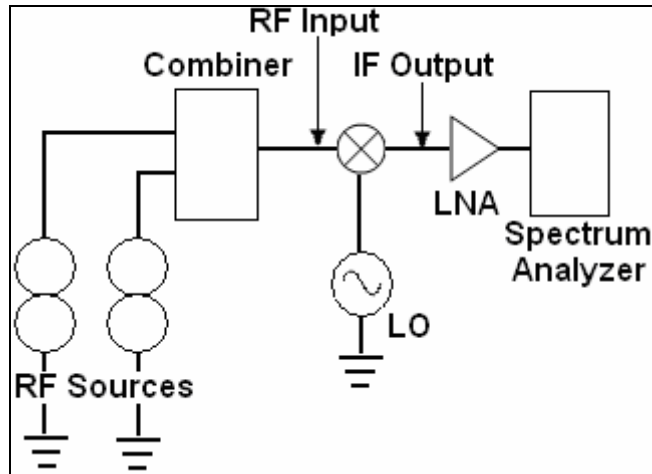
Figure 1. Circuit for two-port SFDR measurement setup.

To attain the measurement, two signal generators are used to produce sinusoids of equal strength that differ in frequency by 1.0 MHz from each other or 0.5 MHz from the center frequency. The separation of the signal frequencies is not critical as long as they fall within the frequency range of the first device, which often is a mixer. The difference between the center frequency and the local oscillator (LO) frequency is the analog IF port frequency. The analog IF output is fed into a spectrum analyzer where IMDs are observed when the two-tone signals are strong enough to overdrive the mixer.

The measurement is performed by increasing the input power of the two RF sources equally and then observing the slopes of the first and third order IMDs vs. the increase in RF input power. Figure 2 shows how the output power of the IMDs relates to the input power of the incoming RF signals. The first order IMD will have a slope of 1.00 and the third order IMD will have a slope of 3.00. If these relationships are plotted on the same graph, the difference between where the third order IMD crosses the noise floor and the strength of the first order IMD is, at this point, the SFDR in decibels per milliwatt. An example is shown in figure 3. There are considerable references describing this measurement in more detail (*1–3*).
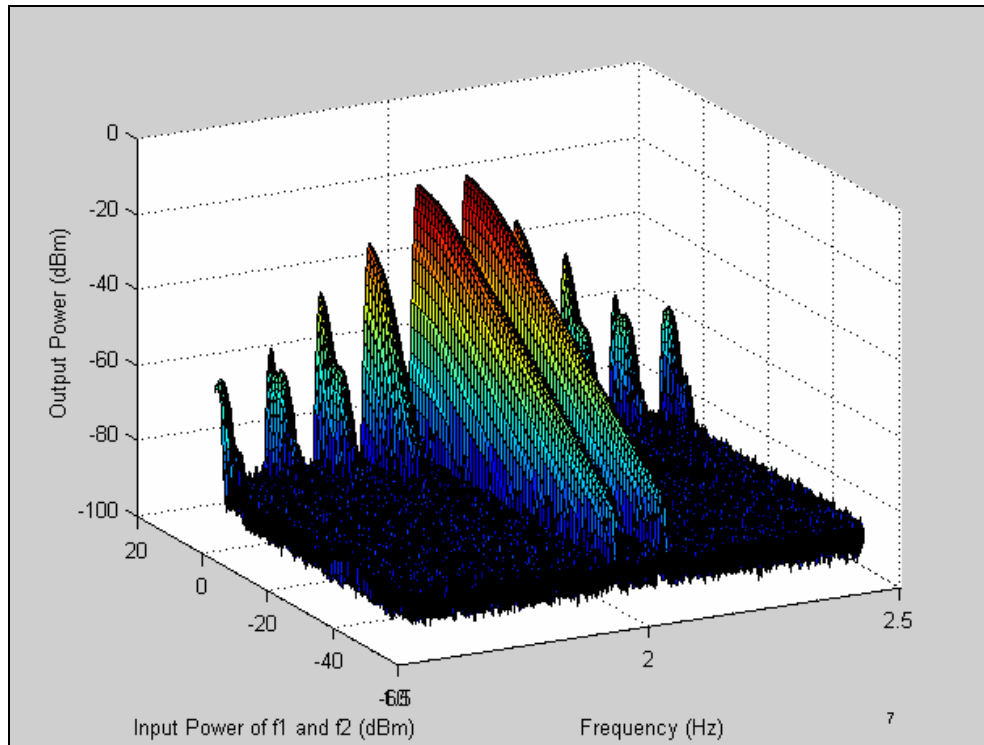
Figure 2. A three dimensional representation of how the 1st, 3rd, 5th, 7th, and 9th order IMDs grow in strength in relation to an increase in the strength of the input signals.
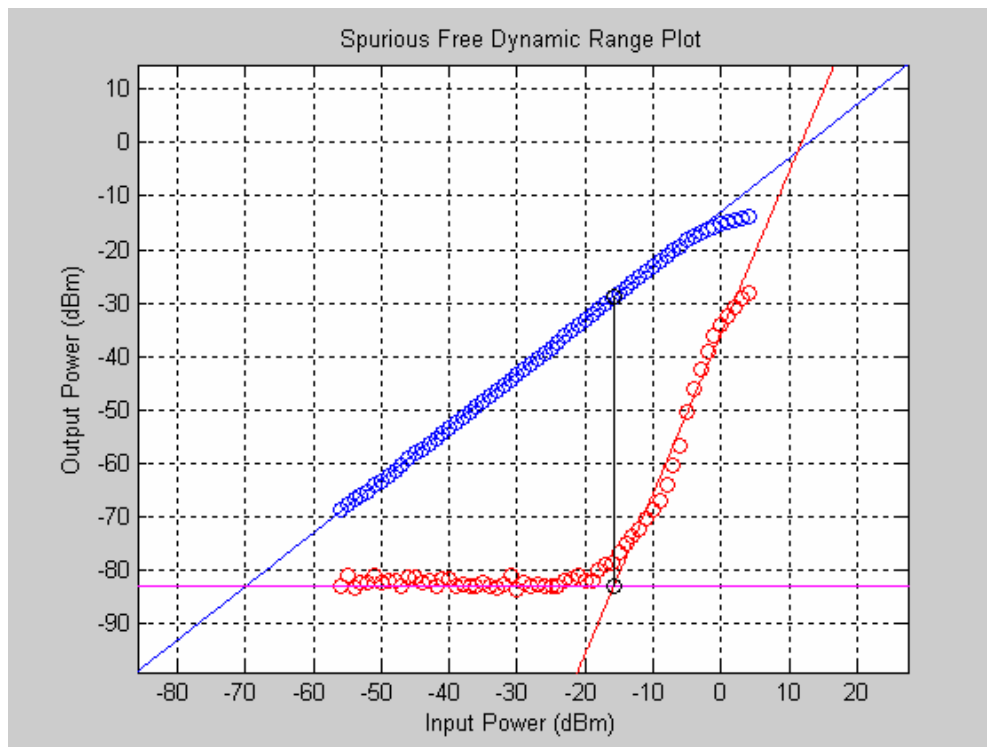

Figure 3. Plot of the linear relationships of the first and third order IMD for the two-port setup performed on mixer ZX05-11X-S. Black indicates where the SFDR value is calculated.

2.2 One-port Measurement Setup

The one-port SFDR measurement setup depicted in figure 4 connects only to the analog RF input. The IF analog output port may not necessarily be available, hence it is not part of the measurement setup. Performing the SFDR measurement using only a one-port setup is a novel approach, because until now two analog ports have been required to make the measurement.
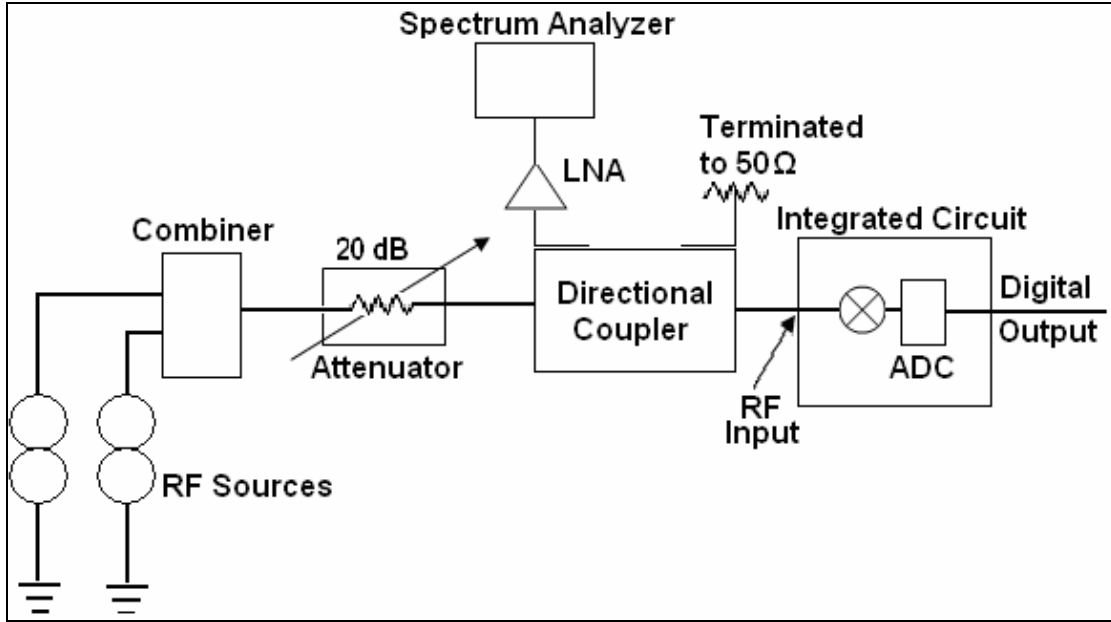
Figure 4. Circuit for one-port SFDR measurement setup.

The RF directional coupler is the critical element needed to convert from a two-port measurement setup to a one-port measurement setup. The choice of the directional coupler is important, because too much isolation between the coupled lines yields more insertion loss or less sensitivity in the dynamic range measurement due to added noise. Similarly, too little isolation means overloading the low-noise amplifier (LNA) and/or the spectrum analyzer input, possibly causing the creation of additional IMDs from these devices. Therefore, it is necessary to remove the IC under test and replace it with a 50Ω load to verify that no additional IMDs are creating interference from elsewhere in the setup. Using this new one-port measurement setup, the SFDR calculations can be performed the same way as described in the two-port measurement description.

Calibration will be required to make sure the true SFDR is measured, and that the extra noise added because of losses in the measurement setup is taken into account. This can be done by comparing a one- and a two-port SFDR measurement using the same mixer, and also by characterizing the losses introduced by the directional coupler used. Our experimental results will demonstrate the differences in the comparative measurement results, thereby showing the need for this calibration.

3. Experimental Results

SFDR measurements were performed on two different mixers with differing characteristics in both frequency range and LO input power. In each case, the SFDR measurement was performed following the criterion described earlier and the same directional coupler was used in all the experiments. Calculations of slope were made using MATLAB and the discrete data points measured off of an Advantest R3271 spectrum analyzer. Here, the graphical results of the dynamic range calculations for both the one- and two-port setups are compared with each individual mixer. The purpose of the extra measurements on an additional mixer is to determine the expected SFDR values using this specific directional coupler. Any deviations in SFDR measurements will be due to the insertion losses introduced by the directional coupler.

Before performing the IMD and SFDR measurements, the two RF signals at 999.5 MHz and 1,000.5 MHz and their difference at 1.0 MHz, were observed on the spectrum analyzer. In the absence of the mixer, any IMDs seen at 1.0 MHz could be generated by the spectrum analyzer (or amplifier, if used). These IMDs would alter the SFDR calculations, and must not occur. For the Advantest R3271 spectrum analyzer, IMDs were observed at 1.0 MHz starting at an input power (at the spectrum analyzer) of 0.0 dBm. When taking into account the 10.0 dB loss of the mixers used in our experiment and the 4.0 dB loss of the combiner, our calculations are only valid for input powers less than 10.0 dBm for the two-port setup and less than 20.0 dBm for the one-port setup. This latter limit will vary depending on the coupling constant of the directional coupler used.

Figures 3 and 5 show the SFDR measurements for both the two- and one-port setups for mixer model ZX05-11X-S. The two-port results are the expected results for this method. The first order slope is calculated as 1.00, while the third order slope is calculated as 3.00, and a SFDR of 54 dB is the final result. The results of the one-port measurement show the large effect that the insertion losses of the directional coupler have on the third order IMD relationship. A first order slope of 0.90 and a third order slope of 2.20 greatly change the SFDR measured at 26 dB. In order to correlate the one-port results with the two-port results, the losses of the directional coupler must be modeled, and the graph of the first and third order IMDs needs to be properly calibrated to offset the effects of the directional coupler on the measurement. This process and the results are to be discussed in a separate report.
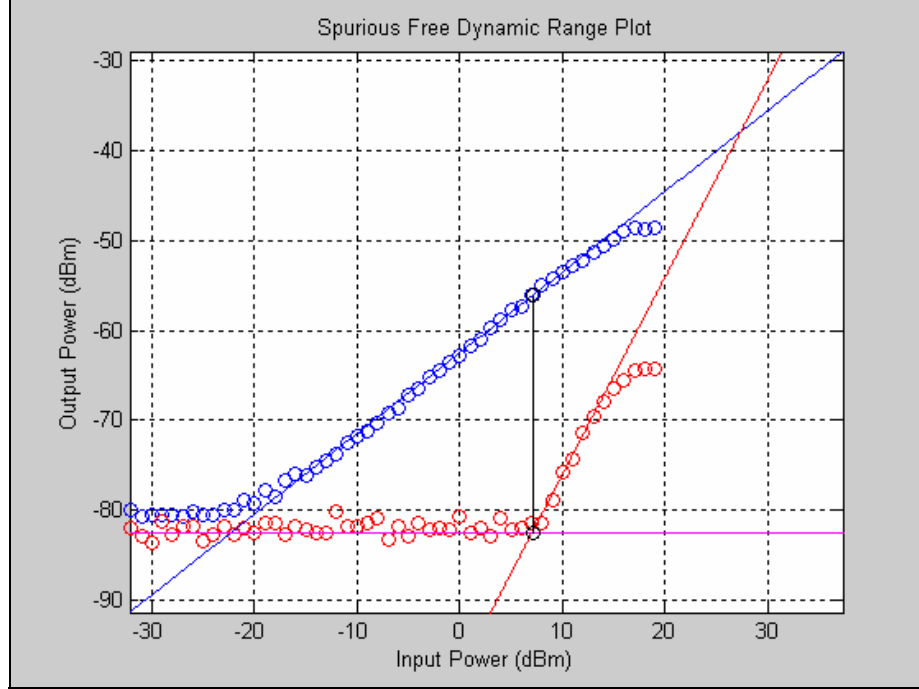
Figure 5. Plot of the same IMD relationships and SFDR calculation for the one-port setup performed on mixer ZX05-11X-S.

The second mixer, model ZX05-10L-S, shows similar results in regard to the differences in the calculated dynamic range for the one- and two-port setups. Figures 6 and 7 show the graphical results of the SFDR measurement for this second mixer. Although the measured SFDR of 55 dBm in the two-port setup is close to the measurement for mixer ZX05-11X-S, this does not imply that separate mixers should necessarily be expected to have similar dynamic ranges. The more important results between the measurements of the two mixers are the deviations in slope and SFDR between the different measurement setups. Since the same directional coupler is used, the deviations are expected to be similar because they are governed by the insertion losses introduced by the directional coupler, and not based on any characteristics of the different mixers. Table 1 shows the measurements for the mixers side-by-side and confirms the deviations are closely related.

There is a 28–31 dB shift in SFDR when using the one-port setup, underlining the necessity of performing a calibration to factor in the directional coupler losses. The difference between the one-port SFDR measurements mainly corresponds to the differences between the change in third order slope for the one- and two-port measurements of each mixer. However, the relative change in third order slope for both mixers differs by only 1.6%, which indicates the SFDR shift experienced by using the one-port setup, in comparison to the two-port setup, is closely correlated to the directional coupler used and not the type of mixer. In addition, the 0.3 dBm difference in the noise floor threshold accounts for approximately a 0.9% change in the measured SFDR since this threshold governs at what input power the third order IMDs break out of the noise floor.
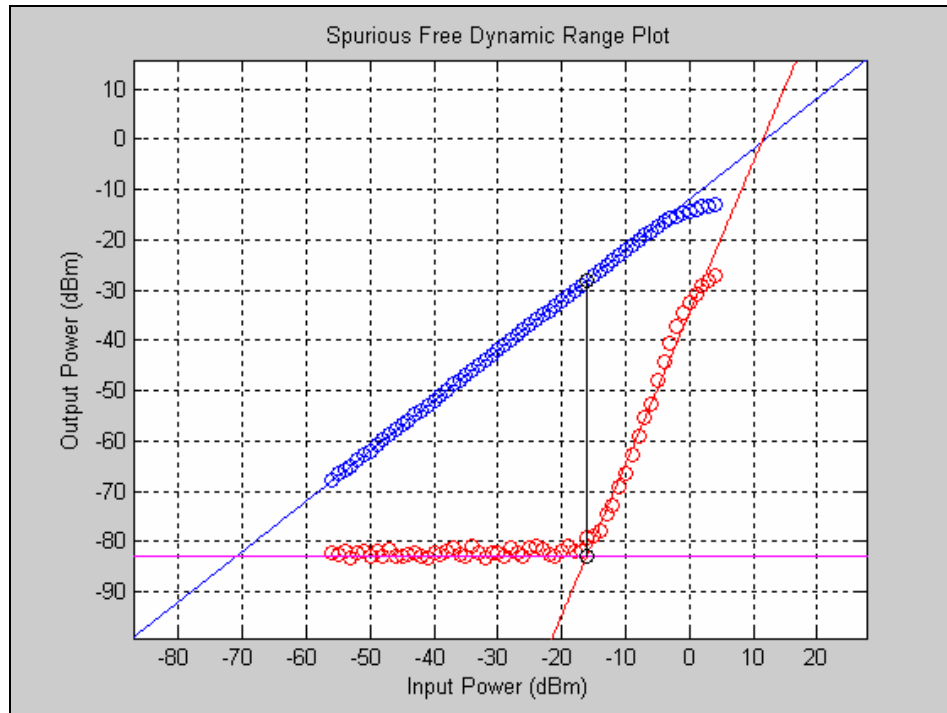
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Figure 6. Plot of the IMD relationships and SFDR calculation for the two-port
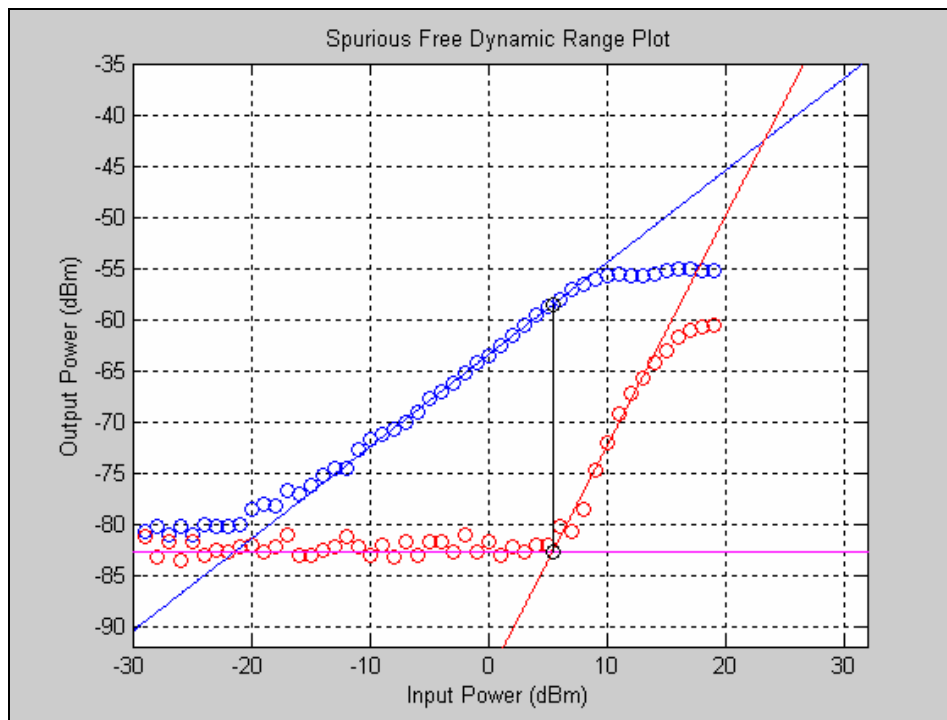measurement setup performed on mixer ZX05-10L-S.

Figure 7. Plot of the same IMD relationships and SFDR calculation for the one-port
setup performed on mixer ZX05-10L-S.

Table 1. Collaborative results of both the one- and two-port measurement setups.

Mixer	Setup	Noise floor	IP1 Slope	IP3 Slope	SFDR
ZX05-11X-S	two-port	–82.5 dBm	1.00	3.00	54 dBm
	one-port	–82.5 dBm	0.90	2.20	26 dBm
ZX05-10L-S	two-port	–82.8 dBm	1.00	3.00	55 dBm
	one-port	–82.8 dBm	0. 90	2.25	24 dBm

4. Conclusion

This is a preliminary report on a novel one-port SFDR measurement setup for RF analog-in/digital-out ICs such as ZigBee chips and others used in software controlled radio architectures. The one-port method to measure two-tone IMDs is compared to the results of the two-port method. Our results show that while the one-port measurement setup is effective, calibration is needed to account for the losses introduced by a directional coupler in the one-port setup. Furthermore, calibration measurements will need to be repeated every time the setup is reconfigured to accurately account for these losses.

References

1. Steven Maas. *Microwave Mixers*; Artech House: Dedham, MA, 1986.

2. Gonzalez, Guillermo. *Microwave Transistor Amplifiers*, 2nd ed.; Prentice Hall, Inc.: Upper Saddle River, NJ, 1997; pp 362–364.

3. Radmanesh, Matthew. *Radio Frequency and Microwave Electronics*; Prentice Hall, Inc.: Upper Saddle River, NJ, 2001; pp 554–565.

Abbreviations and Acronyms

ADC   analog-to-digital converter

IC   integrated circuit

IF   intermediate frequency

IMD   intermodulation

LNA   low-noise amplifier

LO   local oscillator

RF   radio frequency

RFID   RF identification

SFDR   Spurious-free dynamic range

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